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COMBINED OPERATING MODES AND STAND TYPES IN TANDEM COLD ROLLING MILLS

The invention concerns a method for the combined operation of individual rolling stands in a tandem cold rolling mill, comprising a pair of work rolls and a pair of backup rolls in the case of four-high rolling stands and, in addition, a pair of intermediate rolls in the case of six-high rolling stands, wherein at least the work rolls and the intermediate rolls interact with axial shifting devices.

In the past, quality requirements for cold-rolled strip with respect to thickness tolerances, attainable final thicknesses, strip crown, strip flatness, surfaces, etc., have steadily increased. In addition, the great variety of products on the market for cold-rolled sheets and plates is leading to an increasingly varied product spectrum with respect to the material properties and the geometric dimensions. Due to this development, there has been an increasing need for more flexible plant conceptual designs and modes of operation in cold tandem trains -- optimally adapted to the final product to be rolled.

The conventional plant conceptual design of a tandem cold rolling mill consists in the arrangement of several four-high rolling stands in succession. The number of stands required is substantially determined by the total reduction and by the final thickness to be produced. In addition to the basic conceptual designs with bending systems and fixed roll crowns as adjusting mechanisms that affect the roll gap, there are basically two other stand conceptual designs that additionally affect the roll gap either by shifting or swiveling the work rolls, which are based on different effective principles:

- technology of strip edge-oriented shifting
- CVC/CVC^{plus} technology
- PC technology (pair cross, i.e, slanting of the work rolls).

The work roll diameter has a considerable influence on the achievement of a desired final thickness and the realization of certain draft distributions (pass program design), especially in the case of relatively high-strength grades. As the diameter of the work roll decreases, the flattening behavior becomes more favorable and the required rolling force is reduced. Factors relating both to the transmission of torque and to the deflection of the roll, however, impose a limit on the extent to

which the diameter can be reduced. If the roll neck cross sections are inadequate for transmitting the driving torques, the work rolls can be driven by the adjacent roll by frictional engagement. Of course, in the case of a four-high rolling stand, heavy driving elements (motor, pinion gear unit, spindles) are necessary to realize a backup roll drive, and these elements make the mill more expensive. Here it makes sense to realize individual stands (usually the leading stands) as six-roll stands with intermediate roll drive.

The flatness of the strip is significantly affected not only by the vertical deflection but also by the horizontal deflection of the work rolls and intermediate rolls. The horizontal shifting of the work rolls and intermediate rolls from the center plane of the stand provides the set of rolls with support of a type which significantly decreases the horizontal deflection.

The rolling process can be additionally influenced with respect to flatness and the roll gap by slanting the work rolls. As is described in JP 57 190 704 for four-high rolling stands, the work rolls and intermediate rolls are simultaneously pivoted relative to each other by the same amount parallel to the plane of the strip around a common pivot point at the center of the roll axis.

In addition, the six-high rolling stand has an additional, rapid adjusting mechanism for intermediate roll bending. In combination with work roll bending, the six-high rolling stand thus has two independent adjusting mechanisms that affect the roll gap. In the first stand, rapid adaptation of the roll gap to the profile of the entering strip for the purpose of avoiding flatness defects is guaranteed. In the last stand, both adjusting mechanisms can be effectively used for flatness control.

Another criterion for the quality of the final product is the surface condition of the exiting strip. The surface of the strip can be systematically predetermined by textured (roughened) and chromium-plated rolls. To prevent marks on the final product caused by the shifting of the wear edges or to prevent ripple on the strip surface caused by the occurrence of relative speed differences across the width of the exiting strip, it is effective to realize the last stand of a tandem cold rolling mill as a six-high rolling stand. The work rolls are cylindrical or are furnished with a slight camber. They are not shifted in the rolling process.

The effective principles described above involve separate stand conceptual designs, since different roll geometries are necessary. In conventional CVC technology, as described in EP

0 049 798 B1, the barrel lengths of the shiftable rolls are always longer than the stationary unshifted rolls by the amount of the axial shifting stroke. As a result, the barrel edge of the shiftable roll cannot be pushed under the stationary roll barrel. Surface damage and marks are avoided in this way. The work rolls are generally supported over their entire length on the intermediate rolls or backup rolls. In this way, the rolling force applied by the backup rolls is transmitted to the entire length of the work rolls. As a result, the ends of the work rolls, which extend laterally beyond the rolling stock and thus are not involved in the rolling process, are deflected towards the rolling stock by the rolling force applied to them. This detrimental deflection of the work rolls causes upward bending of the middle sections of the roll. This in turn results in insufficient rolling out of the central region of the strip and excessive rolling out of the edges of the strip. These effects come into play especially when rolling conditions vary during the operation and when strips of different widths are being rolled.

By contrast, in the technology of strip edge-oriented shifting, as disclosed in DE 22 06 912 C3, rolls with the same barrel length are used in the entire set of rolls. The shiftable rolls are thus provided with a corresponding geometry

at one end in the barrel edge region and with a setback to reduce locally arising load peaks. The effective principle is based on the strip edge-oriented readjustment of the barrel edge, ahead of, at, or even after the strip edge. Especially in the case of six-high rolling stands, the shifting of the intermediate roll below the backup roll allows the effectiveness of the positive work roll bending to be influenced in a systematic way. However, the axial shifting of the rolls in this method has an unfavorable effect on the load distribution in the contact joints. With decreasing strip width, there is a serious increase in the maximum load peak of the contact force distribution.

In the patent DE 36 24 241 C2 (Method for Operating a Rolling Mill for the Production of Rolled Strip), the two methods are combined. The objective is to make the unfavorable deflection of the work rolls under rolling force more uniform over the entire spectrum of strip widths and to increase the effectiveness of the roll bending systems while shortening the shift distances without having to interrupt the continuous rolling operation. This objective is achieved by the strip edge-oriented shifting of intermediate rolls or work rolls with an applied CVC cross section. The barrel edges of the CVC rolls are positioned in the region of the strip edge. As in the case

of the technology of the strip edge-oriented shifting, the set of rolls comprises rolls of equal barrel lengths.

For reasons of economy, an effort is made to realize all of the stands the same, if possible, in order to reduce the expense of maintenance and replacement parts. In the past, therefore, tandem cold rolling mills were designed with the conventional plant layout or with the described technologies throughout.

The objective of the invention is to realize these technologies/operating modes by a stand conceptual design with a geometrically identical set of rolls that is not limited only to a six-high rolling stand and not only to the intermediate rolls.

The objective with respect to the method is achieved with the characterizing features of Claim 1 by the combined use of the following technologies within the multiple-stand tandem cold rolling mill:

- use of CVC/CVC^{plus} technology with CVC roll contours of higher order, wherein each work roll/intermediate roll has a barrel lengthened by the amount of the shifting stroke;
- use of pair-cross (PC) technology, wherein each work roll/intermediate roll can be swiveled parallel to the plane of the strip;

• use of strip edge-oriented shifting of the work rolls/intermediate rolls, wherein each work roll/intermediate roll has a barrel which is lengthened by the amount of the shifting stroke and which has a cylindrical or cambered cross section, and the work rolls/intermediate rolls are each shifted from the neutral shift position by the same amount symmetrically to the center of the stand in the direction of their axes of rotation.

An installation for carrying out the method of the invention is characterized by the features of Claim 5.

The roll configuration from CVC/CVC^{plus} technology for a six-high roll stand or four-high roll stand is used as the basis for the stand conceptual design. The shiftable intermediate roll or work roll has a barrel that is longer by the CVC shifting stroke and is positioned symmetrically in the center of the stand for the neutral shift position.

The work roll/intermediate roll with a longer and symmetrical barrel is used during the strip edge-oriented shifting either with a cylindrical or cambered cross section. By suitable design of a setback in the region of the barrel edge in combination with the superimposed roll cross section and the strip width-dependent optimization of the axial shift position,

the deformation behavior of the set of rolls and the effectiveness of the positive work roll bending (six-high rolling stand) can be systematically influenced, and the optimum roll gap can be adjusted.

In addition, barrel regions within the set of rolls are systematically shielded from the distribution of forces by optimization of the shift position of the work rolls/intermediate rolls. Deformations with negative effects that result from this are reduced, since the "principle of the ideal stand" is approached. However, the load distributions that occur in the respective contact joints increase due to the reduced contact lengths.

The stand conceptual designs described above are modified in accordance with the invention in such a way that the roll gap is controlled either by the shifting or the swiveling of the work roll/intermediate roll. A six-high rolling stand is absolutely necessary whenever an additional adjusting mechanism for controlling the edge drop of the strip is to be implemented in the stand. Two mutually independent shifting systems for the profile and flatness are needed for this purpose. The plant layout is substantially determined by these criteria. Depending on the requirements established for the rolling process, the range of plant configurations extends from conventional tandem

cold rolling mills consisting of four-high rolling stands, to combined plants consisting of four/six-high rolling stands, to tandem cold rolling mills that consist exclusively of six-high rolling stands. The basic approach for realizing a strip edge-oriented shifting strategy exclusively of the intermediate rolls and exclusively in a six-high rolling stand with the use of a geometrically identical set of rolls was described in detail in DE 100 37 004 A1.

Further advantages, details, and features of the invention are apparent from the following explanations of the various specific embodiments that are schematically illustrated in the drawings. For the sake of clarity, the same rolls are provided with the same reference numbers.

-- Figure 1 shows the geometry of the intermediate roll without roll cross-sectional shaping in a six-high rolling stand.

-- Figure 2 shows the geometry of the work roll without roll cross-sectional shaping in a four-high rolling stand.

-- Figure 3 shows the one-sided setback in the area of the barrel edge of a work roll/intermediate roll.

-- Figure 4 shows a stand conceptual design with a lengthened intermediate roll barrel.

-- Figure 5 shows a stand conceptual design with a lengthened work roll barrel.

-- Figures 6a-6c show positioning of the intermediate roll setback.

-- Figures 7a-7c show positioning of the work roll setback.

Figures 1 and 2 show the geometry of the intermediate roll/work roll 11, 10 without roll cross sectional shaping. In Figure 1, the shiftable intermediate roll 11, which has a lengthened barrel, is positioned symmetrically with respect to the center of the stand Y-Y between the work roll 10 and the backup roll 12 in the neutral shift position $s_{ZW} = 0$. In Figure 2, the work roll 10 has a lengthened barrel and is likewise positioned symmetrically with respect to the center of the stand Y-Y in the neutral shift position $s_{AW} = 0$.

Figure 3 shows a schematic representation of the appearance and the geometric configuration of a one-sided setback d in the region of the barrel edge of a work roll/intermediate roll 10, 11. A one-sided setback, as used here, is already described in detail and illustrated by a drawing in DE 100 37 004 A1.

The length l of the one-sided setback d in the region of a barrel edge of the work roll/intermediate roll 10, 11 is divided into two adjacent regions a and b. In the first, inner region a, beginning at point d_0, the setback y(x) obeys the equation of

the circle $(l - x)^2 + y^2 = R^2$, where R is the radius of the roll. A value d(x) of the setback d of:

Region a:

$= (R^2 - (R - d)^2)^{1/2} \quad \Rightarrow \quad d = d(x) = R - (R^2 - (l - x)^2)^{1/2}$

is then obtained for the region a.

If a minimally necessary diameter reduction 2d, which is predetermined as a function of external boundary conditions (rolling force and the resulting roll deformation), is reached, the setback d will run linearly as far as the barrel edge, so that the following is obtained for the region b:

Region b:

$= l - a \quad \Rightarrow \quad d = d(x) = \text{constant}$

The transition between region a and region b can be made with or without a continuously differentiable transition. In addition, this transition of the setback can also be made with a sequential setback of the dimension d resulting from the flattening according to a predetermined table. The setback d is then flatter, for example, in the transition region, than a radius and is very much steeper at the end. For reasons related to grinding technology, the transition to the cylindrical part is made with a correspondingly greater step in the transition

between a and b (about 2d).

The diameter reduction 2d by the setback is made in such a way that the work roll 10 in a six-high rolling stand can bend freely by the setback d of the intermediate roll 11 without any worry about contact in the region b. In a four-high rolling stand, the setback d serves only for local reduction of the load peaks that arise.

The one-sided setback is normally located on the service side BS for the upper work roll/intermediate roll 10, 11 and on the drive side AS for the lower work roll/intermediate roll 10, 11, as illustrated in Figures 4 and 5. However, the effective principle remains the same if the setback d is placed in the opposite way on the drive side AS for the upper work roll/intermediate roll 10, 11 and on the service side BS for the lower work roll/intermediate roll 10, 11.

Figures 6a to 6c show the axial shifting of the intermediate roll 11 by a shifting stroke m. In Figure 6a, the beginning d_0 of the setback d is positioned outside the strip edge (m = +), in Figure 6b, it is positioned at the strip edge (m = 0), and in Figure 6c, it is positioned inside the strip edge (m = -), i.e., already within the width of the strip. The positioning depends on the strip width and the material properties, so that the elastic behavior of the set of rolls and

the effectiveness of the positive work roll bending (six-high rolling stand) can be systematically adjusted.

Finally, Figures 7a to 7c show the strip edge-oriented shifts of the work roll 10, which are carried out in the same way as for the intermediate roll 11 in Figures 6a to 6c.

In different strip width ranges, the shift position is predetermined by piecewise-linear step functions, on which the different positions of the beginning d_0 of the setback d relative to the strip edge are based.

The essential advantage of the stand conception that has been described is that the CVC/CVC^{plus} technology and the technology of the strip edge-oriented shifting can be realized with only one geometrically identical set of rolls. Different roll types are no longer necessary. The only differences that still exist are in the roll cross section that is provided or in a setback according to predetermined values found as described above. In addition, there is the possibility of combining the two technologies with swiveling of the work rolls/intermediate rolls in the plane of the strip.

<u>List of Reference Symbols</u>

10	work roll
11	intermediate roll
12	backup roll
14	rolled strip
a	first, inner segment length of d
b	second, outer segment length of d
d	setback
d_0	beginning of d
d(x)	value of d as a function of x
l	length of d
m	shifting stroke
s_{AW}	amount of shift of a work roll
s_{ZW}	amount of shift of an intermediate roll
x, y	Cartesian coordinates
AS	drive side
BS	service side
R	roll radius
R_0	initial roll radius
X-X	axis of rotation
Y-Y	center of the stand